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Virtual reality simulator for phacoemulsification cataract surgery education and training

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Abstract

Computer systems are taking an important role in the field of medicine with the introduction of electronic biomedical devices in diagnosis and treatment, where medical records obtained from the devices are documented and processed as reference to medical panels. The capability of latest computed tomography technology in generating three-dimensional patient model for graphical representation is very informative for surgeons to plan and make decision before the operation. This initiates the idea of implementing the model into computer-generated simulator for surgical education and training. This paper presents the development of virtual reality cataract surgery simulator. Three-dimensional eye model and surgical instruments are generated as the virtual surgical environment. The system is equipped with a pair of haptic devices to provide actual sensation. The results show that the simulator is capable of providing interactive training on the main procedures of cataract surgery. It has the potential to be incorporated as part of the curriculum of medical program when the proposed future work in the end of the paper is completed.

Keywords: cataract surgery; phacoemulsification; surgical simulator; virtual reality.

1. Introduction

Virtual reality is usually classified as a computer-simulated environment that responds to human activities. It has been implemented into different areas not limited to scientific research, education and training, product evaluation, safety measurement and entertainment. This system normally consists of a computer that renders three-dimensional virtual world in real-time, a position tracking controller and a head-mounted stereoscopic display [1]. Visual and auditory are the two elements found in most of the virtual environments in providing sensation of actual interaction with the virtual world [2]. A higher level electronically simulated medium is able to generate faithful force feedback with the aid of the latest implementation of haptic interface in virtual reality. A real-world phenomenon can be replicated into the virtual environment with the objective to provide specific exposure, training or treatment for the users in a protected and controlled medium, where severe injury and lost of property that may happen in actual situation are avoidable.

The growth of electronics and computer technology has contributed to the development of virtual reality surgical training tool. Medical simulation has become a valuable learning and practicing tool in training and teaching skills for various types of surgery. This is due to the limitations occur in the traditional training on

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animals and human cadavers. Animals do not possess the same anatomy as human beings, the samples usually are expensive and not reusable. Despite the fact that human cadavers have the correct anatomy, they are difficult to procure, expensive and prone to tissue degradation problems [3]. Surgical training simulators that are available in the market for surgery such as endoscopic surgery [4], endovascular surgery [5] and laparoscopic surgery [6], have received constructive response from some clinical validation reports. This evidence shows that virtual reality simulator has potential to be incorporated into the curriculum of surgical training and assessment for the coming years.

This article focuses on the research and development of a cataract surgery simulator, with the aim to serve the purpose of providing repetitive training on the main procedures of phacoemulsification surgery. Preliminary results concerning the realization of corneal incision, capsulorhexis, phaco-sculpting and intraocular lens (IOL) implantation are described. Tissue deformation and topological modification are modelled and simulated with response to the actions performed on the pair of haptic devices that is equipped to the system. The article is organized in four sections. Section 2 presents an overview on cataract surgery. The system architecture of the cataract surgery simulator is addressed in Section 3. Section 4 shows the simulation of four main cataract surgery procedures, corneal incision, capsulorhexis, phaco-sculpting and IOL implantation. Section 5 outlines the conclusion of this research work and suggests future improvement and development.

2. Cataract and Surgical Treatment

Cataract is the clouding of the lens in the eye that influences vision. Most of the cataract formed inside the patient's eye is age-related cataracts. This is usually caused by the protein in the lens clumps up which reduces the light from reaching the retina and produces blurred vision. Besides that, diabetes, glaucoma, ocular inflammation, radiation and smoking are some of the risk factors that lead to the formation of cataract.

Phacoemulsification is the modern cataract surgery, which is introduced by Dr. Charles Kelman in the late of 1960s [7]. The main advantage of this technique is the incision required for the procedure is small and usually self-sealable. The visual recovery period after the operation can be shorten effectively. Phacoemulsification cataract surgery begins with topological anesthetic, where anesthetic gel is instilled in the eye pre-operatively. A side port incision is made for the injection of viscoelastic to hold open the space between the cataract and the delicate underside of the clear cornea in front of it. The operation continues with corneal incision, ophthalmologist uses keratome to make an incision of 2.2 mm to 2.5 mm wide on temporal limbus as the tunnel for insertion of other surgical instruments. Anterior surface of the capsule that lies on top of the nucleus is removed after that, which the procedure is named as capsulorhexis. The layer is torn by using forceps to create a round shape opening for the removal of cataract. Cataract in the eye is divided into four quadrants by using divide and conquer technique. Phaco handpiece with steel needle emulsifies the cataract into small pieces while the aspiration port at the tip of the probe removes the fragments by suction from the pump. The surgery is completed by removing the soft cortex and implanting foldable IOL of appropriate power into the capsular bag.

3. System Architecture and Development

The developed cataract surgery simulator is carried out in a personal computer with hardware configuration of Intel Core i7-2600 CPU, 8GB DDR-3 RAM and NVIDIA GeForce GTX560 Ti graphics card. A pair of SensAble Phantom Omni haptic devices is equipped into the system to provide the control of virtual surgical instruments and generate faithful force feedback. The devices consist of six degrees-of-freedom in position tracking and three degrees-of-freedom for force feedback, which are adequate to be used as human-computer interface for the simulation. The surgical training platform of phacoemulsification cataract surgery simulator is shown in Fig 1. Haptic worlds are created in the system to obtain the contact point and force from both of the styli's movements respectively. The information of the styli is processed by simulation system to identify the types of surgical activity such as cutting, grasping, pulling, pushing, sculpting and emulsifying. Besides that, reaction force is also computed and sent to the haptic devices at the same time. Modelling system identifies and updates the tissue deformation and topological modification on the mesh of eye model. The changes on the eye ball will be generated into three-dimensional images and outputs to the users via computer display. Fig 2 outlines the system architecture of the surgical training simulator.

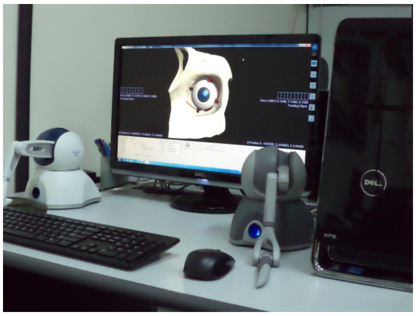


Fig. 1. Phacoemulsification cataract surgery simulator.

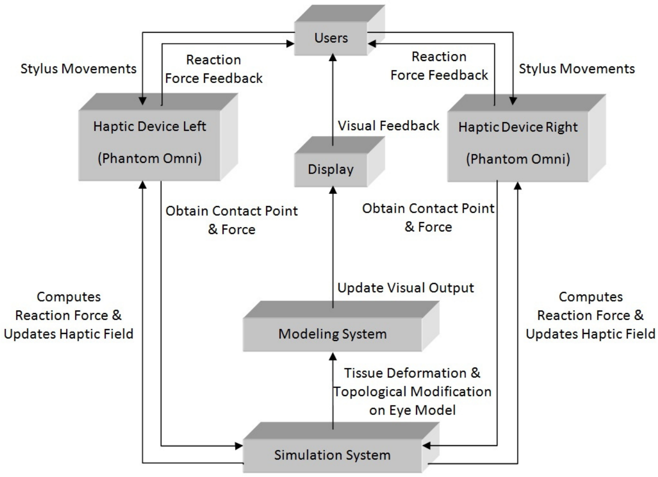


Fig. 2. System architecture.

Human eyeball and surgical instruments, which are the main objects to be visualized in the virtual surgical environment of simulator are designed by using a 3D modelling, animation and rendering software named Autodesk 3ds Max. Cornea, iris, lens, sclera and extraocular muscles are the parts of eye that have been designed for the simulation along with surgical instruments such as keratome blade, hook, forceps, phaco probe and IOL injector. The virtual objects are saved in OBJ format as the information of vertices and triangular facets are used to represent the mesh of the three-dimensional models. In order to improve the visual realism of the virtual surgical environment, rotational movements of eyeball and extraocular muscles are implemented into the simulator with response to the force that is applied from the virtual surgical instrument [8].

An interactive graphical user interface (GUI) is designed in the developed simulator in order to provide an appropriate platform for medical residents and ophthalmologists to conduct surgical training effectively. GLUI library, which is a GLUT-based user interface library embedded in OpenGL, is used to develop the interface. Features such as selections of eye anatomy and surgical instruments together with controls of three-dimensional view are implemented in the GUI. As the intention to develop a more user-friendly simulator, a graphical force indicator is created to show the value of force applied on the surface of eyeball model. The colored force bar varies in length by referring to the reading obtained from the simulation system. This feature allows users to monitor their action when manoeuvring virtual surgical instrument through haptic device, thus reduces error in damaging ocular tissue unintentionally.

4. Results

4.1. Corneal Incision

Small incisions have to be made in the beginning of cataract surgery. The tunnels on temporal limbus are the place where forceps, phaco probe and IOL injector can be inserted into the eye to carry out subsequent procedures. The surface of cornea is represented by using triangular surface mesh. Virtual keratome blade in the simulation is controlled by manoeuvring the stylus of the haptic device. When the resultant force applied on surface of the cornea exceeds the penetration force threshold, the contact point between the tool and the surface is classified as cutting point and the vertices surrounding the contact point are grouped to form a cutting mesh. The tunnel is created by leaving a distance between the triangular facets that belongs to the cutting mesh and positioned around the region of cutting point. The simulation of corneal incision is illustrated in Fig 3.

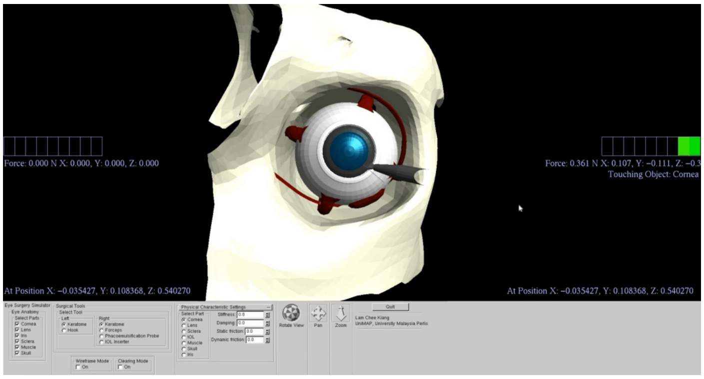


Fig. 3. Corneal incision.

4.2. Capsulorhexis

The outermost layer of the lens, anterior capsule, has to be removed during the operation in order to provide an opening for phaco probe to access into the nucleus of lens and emulsify the cataract. Anterior capsule in the simulation is represented by a thin layer of triangular mesh model. The vertices are connected to other surrounding vertices by using mass-spring system. Fig 4 demonstrates the operation of capsulorhexis by using forceps. Grasping point is identified when the virtual forceps clipping on the surface of capsule. Vertices that are close to the grasping point are pulled in response to the force and its direction, which is obtained from the reading of haptic device. Due to this, the springs which are connected between the vertices, transfer its force to the adjoining vertices just like the intention to move them. Effect of tearing occurs when resultant force has overcome the breaking point of springs that connect the vertices. The flap of the anterior capsule is pulled by the forceps gently and carefully until a round shape tear is formed on the lens.

4.3. Phacoemulsification

Divide and conquer nucleotomy is most commonly used for phaco-sculpting procedure. It involves the dissection of nucleus into quadratic sections. The phacoemulsification training begins by making a trench on the cataract using the virtual phaco probe, where deep sculpting is performed across the centre of nucleus. The facets touched by the tip of the tool are removed when the phaco dynamic of the system is activated. After a trench is made, the nucleus is required to be rotated at 90 degrees in order to create a cross shape trench and separate the nucleus into four equal parts. The nucleus can be rotated in anti- or clockwise direction depending on the direction of forces applied from the pair of haptic devices. The emulsification of each quadrant starts after the nucleus is divided. The fragments that fall into the spherical zone in front of the tip of phaco probe are sucked out by aspiration. This procedure is considered complete when fragments of cataract are removed from the eye. Fig 5 shows the different stages of phacoemulsification procedure.

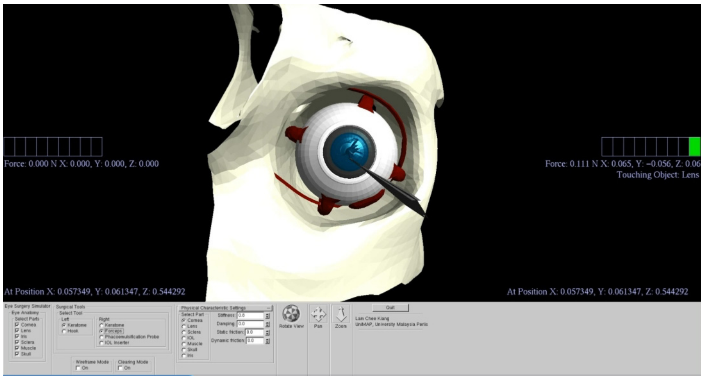


Fig. 4. Capsulorhexis.

As the purpose to imitate the sensation of phaco dynamic, which is produced by irrigation and aspiration of phaco probe in real cataract surgery, mild vibration is generated by the system and it can be felt on the stylus of the haptic device. In addition, a virtual medium with viscous effect is created inside the eyeball model to replicate the actual feeling of manoeuvring the surgical instruments covered by aqueous humour. These two effects are important in improving the haptic realism of the cataract surgery simulators; therefore medical residents and ophthalmologists can adapt themselves into the virtual surgical training more readily and comfortably. The simulator will warn the users if the surgical instrument touches some sensitive parts of the eye that may cause ocular damage or surgical trauma on patient.

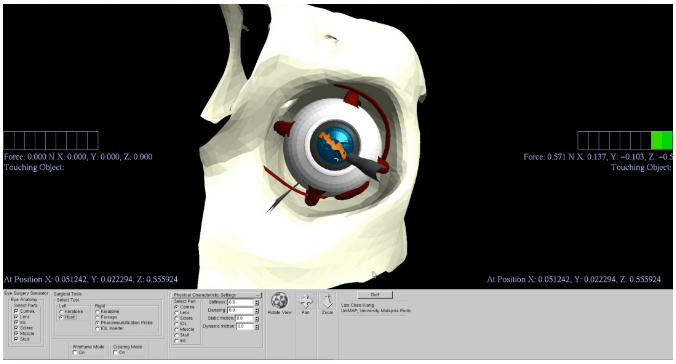
4.4. IOL Implantation

An intact posterior capsule is left behind after phacoemulsification for providing support for the IOL, which replaces the clouded crystalline lens to focus sharp image on the retina. A specially designed injector is used as the insertion device for IOL implantation. Refractive power correction is incorporated in the recent invention of multifocal IOL, allowing focus of both distant and near images on retina. A lens injector as illustrated in Fig 6 is designed virtually to replicate the actual process. Ophthalmologists are able to familiarize themselves on the techniques of inserting the IOL and positioning it into capsular bag.

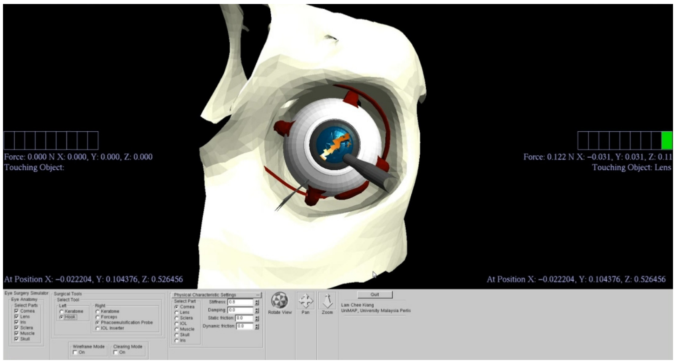
5. Conclusion

This paper presents a virtual reality cataract surgery simulator that is capable of providing education and training for medical residents and ophthalmologists. The main procedures of phacoemulsification cataract surgery are implemented into the system, where precise representation of the anatomy and physiology of the human eye is simulated computationally efficient. The surgical platform consists of interactive user interface and guidance which reduces the complexity in getting used to the training tool.

The main upcoming development of the simulator is the application of surgical training and skill assessment system. Criteria-based training module will be used to evaluate the performance of users along the virtual surgical operation. The purpose of this system is to differentiate the level of competency by comparing the surgical performance of the users. Proficiency of individuals can be increased by repetitive training using the simulator before they are assigned to the real surgical task. Professional and experienced ophthalmologists will be invited to conduct usability study. Experimental result and information obtained from the experts will be used to enhance the surgical simulator and benchmark the performance evaluation system. Clinical validation is planned to be carried out when the development of the simulator reaches the final stage. Medical panels from different levels and years of service in ophthalmology will be recruited to compare the difference of efficiency between traditional wet-lab training and computer-simulated virtual training simulator. The goal is to demonstrate the reliability and validity of cataract surgery simulator as part of the curriculum of medical training program.



(a)



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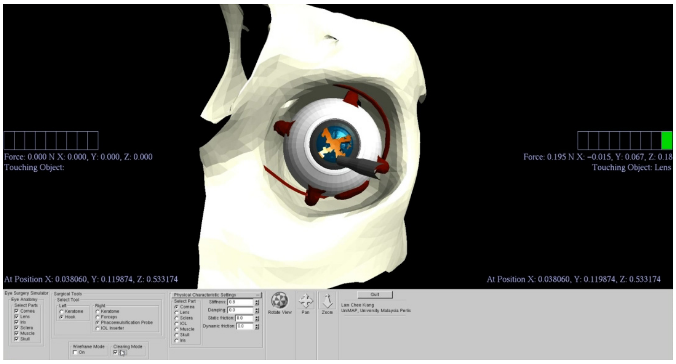

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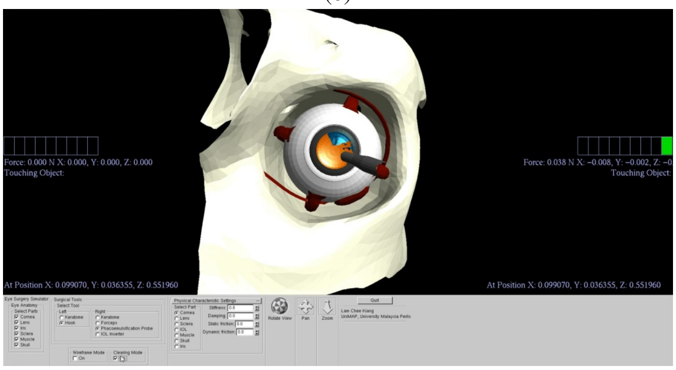

(d)

Fig. 5. Stages of phacoemulsification. (a) Trench, (b) nucleus rotation, (c) cross-trench and (d) emulsification.

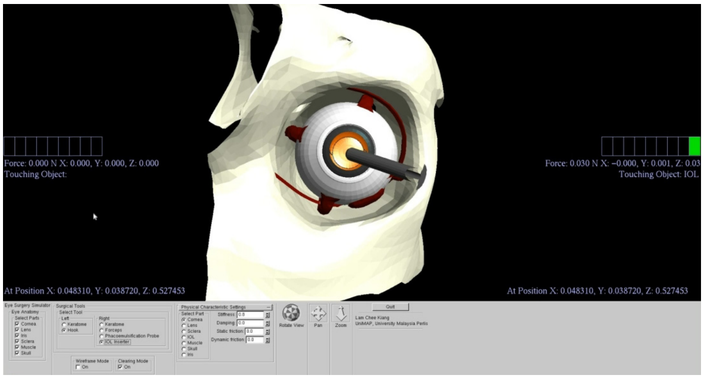

Fig. 6. IOL implantation.

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References

[1] J. Steuer, Defining virtual reality: Dimensions determining telepresence, Journal of communication 42 (4) (2006) 73–93.
[2] K. Stanney, G. Salvendy, Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda, International Journal of Human-Computer Interaction 10 (2) (1998) 135–187.
[3] C. Luciano, P. Banerjee, T. DeFanti, Haptics-based virtual reality periodontal training simulator, Virtual reality 13 (2) (2009) 69–85.
[4] K. Van Sickle, L. Buck, R. Willis, A. Mangram, M. Truitt, M. Shabahang, S. Thomas, L. Trombetta, B. Dunkin, D. Scott, A multicenter, simulation-based skills training collaborative using shared gi mentor ii systems: results from the texas association of surgical skills laboratories (tassl) flexible endoscopy curriculum, Surgical endoscopy 25 (9) (2011) 2980–2986.
[5] I. Van Herzeele, R. Aggarwal, Virtual reality simulation in the endovascular field, Interventional Cardiology (2008) 41–45.
[6] E. McDougall, F. Corica, J. Boker, L. Sala, G. Stoliar, J. Borin, F. Chu, R. Clayman, et al., Construct validity testing of a laparoscopic surgical simulator, Journal of the American College of Surgeons 202 (5) (2006) 779–787.
[7] C. Kelman, The history and development of phacoemulsification, International ophthalmology clinics 34 (2) (1994) 1–12.
[8] C. Lam, K. Sundaraj, M. Sulaiman, Virtual simulation of eyeball and extraocular muscle reaction during cataract surgery, Procedia Engineering 41 (2012) 150–155.